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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

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INFLUENCE OF TAIL LENGTH UPON THE SPIN-RECOVERY

CHARACTERISTICS OF A TRAINER-TYPE-AIRPLANE MODEL

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SUMMARY

An investigation has been conducted to determine the effect of tail
length on the spin and recovery characteristics of a model typical of a
trainer-type airplane. The model used in the investigation was tested
with two tail lengths, and the model having the shorter tail length was
tested with several ventral fins installed in order to improve its recovery
characteristics.

The investigation showed that the model with the longer tail length
had the better recovery characteristics even when the short-tail model
had comparable or even higher values of tail-damping power factor.

INTRODUCTION

Reference 1 presents a method for designing an airplane for satis-
factory spin recovery based upon an empirical relationship between a tail-
damping power factor and relative density and mass distribution. Results
of recent investigations in the Langley 20-foot free-spinning tunnel have
indicated that tail length may have a greater influence on the spin-
recovery characteristics of airplanes than is usually indicated by the
tail-damping power factor. The present investigation was undertaken to
obtain further information on the effect of tail length. The model used
for the investigation was considered representative of a typical single-
engine trainer-type airplane with regard to both dimensional and mass
characteristics. Two values of tail length and several values of tail-
damping power factor were investigated. Erect spins only were tested.

SYMBOLS

b wing span, feet

l tail length, distance from center of gravity to
rudder hinge line, feet

S   wing area, square feet

$\bar{c}$ mean aerodynamic chord of wing, feet

$x/\bar{c}$ ratio of distance of center of gravity rearward of
                            leading edge of mean aerodynamic chord of wing
                            to mean aerodynamic chord of wing

$z/\bar{c}$ ratio of distance between center of gravity and fuse-
                            lage reference line to mean aerodynamic chord of
                            wing (positive when center of gravity is
                            below fuselage reference line)

m   mass of airplane, slugs

I_X, I_Y, I_Z moments of inertia about X, Y, and Z body axes,
                            respectively, slug-feet^2

$\dfrac{I_X - I_Y}{mb^2}$ inertia yawing-moment parameter

$\dfrac{I_Y - I_Z}{mb^2}$ inertia rolling-moment parameter

$\dfrac{I_Z - I_X}{mb^2}$ inertia pitching-moment parameter

ρ air density, slug per cubic foot

μ relative density of airplane $\left(\dfrac{m}{\rho S b}\right)$

α angle between fuselage reference line and vertical
                            (approximately equal to absolute value of angle
                            of attack at plane of symmetry), degrees

ϕ angle between span axis and horizontal, degrees

V   full-scale true rate of descent, feet per second

Ω full-scale angular velocity about spin axis, revolutions
                            per second

TDR   tail-damping ratio (fig. 1 of reference 1)

URVC   unshielded rudder volume coefficient (fig. 1
                  of reference 1)

TDPF   tail-damping power factor (fig. 1 of ref-
                  erence 1)

APPARATUS AND METHODS

Model

The model used for the investigation was arbitrarily considered to be a $\frac{1}{18}$-scale model of a typical trainer airplane, and the dimensional characteristics of the corresponding full-scale airplane are given in table I. Figure 1 is a three-view drawing of the model with the long tail length. The long and short tail lengths investigated are shown in figure 2. When the tail length was decreased, the horizontal tail was raised and a 0.50-inch ventral fin was added in order to maintain approximately the same values of tail-damping ratio and unshielded rudder volume coefficient (fig. 1 of reference 1) for both the long and short tail lengths. (See table II.) The three ventral fins investigated on the model having the short tail length are shown in figure 3.

The model was ballasted with lead weights to obtain dynamic similarity to the corresponding airplane at an altitude of 10,000 feet ($\rho = 0.001756$ slug/cu ft). A remote-control mechanism was installed in the model to actuate the rudder and elevator for recovery tests. Sufficient hinge moments were applied to the controls during recovery attempts to reverse them fully and rapidly.

Wind Tunnel and Testing Technique

The tests were performed in the Langley 20-foot free-spinning tunnel, the operation of which is, in general, similar to that described in reference 2 for the 15-foot free-spinning tunnel except that the model-launching technique has been changed. With the controls set in the desired position the model is now launched by hand with rotation into the vertically rising air stream. After a number of turns, the model assumes its spin attitude and is maintained at a specified level in the tunnel by adjusting the airspeed so that the rate of descent of the model corresponds to the velocity of the vertically rising air stream. The model is shown spinning in the Langley 20-foot free-spinning tunnel in figure 4.

After a number of turns in the established spin, a recovery attempt is made by moving one or more controls by means of a remote-control mechanism. After recovery, the model dives or glides into a safety net. The spin data obtained from the tests are then converted to corresponding full-scale values by methods described in reference 2.

In accordance with standard spin-tunnel procedure, tests were performed to determine the spin and recovery characteristics for the normal control configuration for spinning (elevator full up, ailerons neutral, and rudder full with the spin) and for other aileron-elevator combinations including neutral and maximum settings of the control surfaces for various model conditions. Recovery was generally attempted by reversal of the rudder from full with the spin to full against the spin. Tests were also performed to determine the effect of small variations in control deflections on recoveries from the normal spin control configuration. For these tests, the elevator was set at only two-thirds full up and the ailerons were set at one-third of the full deflection in the direction conducive to slower recoveries (ailerons against the spin for this model). Recovery from this spin was attempted by reversing the rudder from full with to two-thirds against the spin either alone or in conjunction with moving the elevator to one-third down. This control configuration and movement of the controls is referred to herein as the "criterion spin". The turns for recovery were measured from the time the controls were moved until the spinning rotation ceased. The criterion for a satisfactory recovery from a spin in the spin tunnel has been adopted as

$2\frac{1}{4}$ turns or less based primarily on the loss of altitude of the airplane during the recovery and subsequent dive.

For spins which have a rate of descent in excess of that which can be readily attained in the tunnel, the rate of descent is recorded as greater than the velocity at the time that the model hits the safety net; for example, > 300 feet per second. For these tests, the recovery recorded is somewhat conservative inasmuch as recovery is generally attempted before the model reaches its final steep attitude and while the model is still descending in the tunnel.

PRECISION

The model test results presented are believed to be the true values given by the model within the following limits:

α, degrees . . . . ±1
ϕ, degrees . . . . ±1
V, percent . . . . ±5
Ω, percent . . . . ±2

Turns for recovery:
    When obtained from film records . . . . ±1/4
    When obtained visually. . . . . ±1/2

The preceding limits may have been exceeded for certain spins in which it was difficult to control the model in the tunnel because of the high rate of descent or because of the wandering nature of the spin.

Comparison between model and airplane spin results (references 2 and 3) indicates that spin-tunnel results are not always in complete agreement with airplane spin results. In general, the models spun at a somewhat smaller angle of attack, at a somewhat higher rate of descent, and with $5°$ to $10°$ more outward sideslip than did the corresponding airplanes. The comparison made in reference 2 for 21 airplanes showed that approximately 80 percent of the model recovery tests predicted satisfactorily the corresponding airplane recovery characteristics and that approximately 10 percent overestimated and approximately 10 percent underestimated the airplane recovery characteristics.

Because of the impracticability of ballasting the model exactly and because of inadvertent damage to the model during tests, the weight and mass distribution of the model varied within the following limits:

Weight, percent . . . . 0 to 1 high
Center-of-gravity location, percent $\bar{c}$ . . . . 0 to 1 rearward

Moments of inertia:
   I_X, percent . . . . 1 low to 8 high
   I_Y, percent . . . . 0 to 1 high
   I_Z, percent . . . . 0 to 4 high

The measurement of the mass characteristics were made within the following limits of accuracy:

Weight, percent . . . . ±1
Center of gravity, percent $\bar{c}$. . . . . ±1
Moments of inertia, percent . . . . ±5

The controls were set with an accuracy of $±1°$.

<center>TEST CONDITIONS</center>

Table II lists the various configurations tested on the model. The mass characteristics and inertia parameters for the normal loading condition tested for each model configuration are listed in table III. The inertia parameters are also plotted in figure 5. As discussed in reference 4, plots of these parameters can be used in predicting the relative effectiveness of the controls on the recovery characteristics of the airplane.

The normal maximum control deflections used were:

Rudder, degrees . . . . 30 right, 30 left
Elevator, degrees . . . . 30 up, 10 down
Ailerons, degrees . . . . 19 up, 19 down

RESULTS AND DISCUSSION

The results of the model tests are presented in charts 1 and 2. The results for left and right spins were generally similar and are arbitrarily presented in terms of equivalent right spins. Data are presented in terms of full-scale values at an altitude of 10,000 feet.

The data presented in chart 1 show the effect of varying the tail length of the fuselage. It is apparent from the data presented in the chart that the model with the short tail length $\left(\frac{l}{b} = 0.41\right)$ and the 0.50-inch ventral fin installed had unsatisfactory recovery characteristics based on the "criterion spin", whereas the model with the long tail length $\left(\frac{l}{b} = 0.53\right)$ exhibited excellent recovery characteristics. The tail-damping power factor for these two configurations was approximately the same (table II). Adding larger ventral fins improved the recovery characteristics of the short-tail-length model (chart 2) and when the 1.00-inch ventral fin was installed, the recovery characteristics of the model were considered to be satisfactory. It is of interest to note that the over-all recovery characteristics of the long-tail-length model $\left(\text{TDPF} = 395 \times 10^{-6}\right)$ were better than the recovery characteristics of the short-tail-length model with the 1.00-inch ventral fin installed $\left(\text{TDPF} = 517 \times 10^{-6}\right)$, even though the long-tail-length model had a lower value of tail-damping power factor.

The results of the investigation indicate that the damping in the spin increased as the tail became further removed from the wing. For the short-tail-length model $\left(\frac{l}{b} = 0.41\right)$ the vertical tail and the rearward portion of the fuselage may have been somewhat shielded by the wing during the spin, but when the tail length was increased a greater part of the tail may have become exposed to the air stream and thus have become more effective in damping out the spin rotation. In addition, the extra fuselage side area added when the tail surfaces were moved rearward probably contributed toward improving the spin-recovery characteristics as has been indicated by the work of W. Tye and S. V. Fagg in England.

CONCLUSIONS

Based on the results of the investigation, the following conclusions are made:

1. The recovery characteristics of an airplane may be influenced by the airplane tail length to a greater extent than is indicated by the value of the tail-damping power factor.

2. An increase in tail length offers a more effective means of improving the spin-recovery characteristics than an addition of ventral-fin area.

Langley Aeronautical Laboratory
        National Advisory Committee for Aeronautics
            Langley Field, Va., October 4, 1948

REFERENCES

1. Neihouse, Anshal I., Lichtenstein, Jacob H., and Pepoon, Philip W.:
        Tail-Design Requirements for Satisfactory Spin Recovery.
        NACA TN No. 1045, 1946.

2. Zimmerman, C. H.: Preliminary Tests in the NACA Free-Spinning
        Wind Tunnel. NACA Rep. No. 557, 1936.

3. Seidman, Oscar, and Neihouse, A. I.: Comparison of Free-Spinning
        Wind-Tunnel Results with Corresponding Full-Scale Spin Results.
        NACA MR, Dec. 7, 1938.

4. Neihouse, A. I.: A Mass-Distribution Criterion for Predicting the
        Effect of Control Manipulation on the Recovery from a Spin.
        NACA ARR, Aug. 1942.

TABLE I.-FULL-SCALE DIMENSIONAL CHARACTERISTICS OF THE

AIRPLANE REPRESENTED BY THE $\frac{1}{18}$-SCALE MODEL

Over-all length, ft:
 Long tail length 31.6
 Short tail length 26.7

Wing:
 Span, ft 41.6
 Area, sq ft 236.0
 Aspect ratio 7.4
 Chord, in.
  Root 89.9
  Mean aerodynamic chord 70.7
  Tip (design) 47.0
 Taper ratio (design tip chord, root chord) 0.52
 Location of mean aerodynamic chord, in.
  Leading edge of $\bar{c}$ rearward of leading edge of root chord . . 4.8
  Leading edge of $\bar{c}$ below center line of fuselage 10.9
 Angle of incidence, deg
  Root 3.00
  Mean aerodynamic chord 1.21
  Tip . . . . -1.00
 Angle of geometric dihedral (in wing reference plane), deg . . 5.00
 Angle of sweepback (at leading edge of wing), deg 2.50
 Airfoil section
  Root . . . . NACA 2416
  Tip . . . . NACA 4409

Ailerons:
 Area (both ailerons), sq ft
  Total 20.9
  Rearward of hinge line 15.9
 Span, in. 108.0

Horizontal tail surfaces:
 Area, sq ft
  Total 47.38
 Elevator
  Total 20.08
  Rearward of hinge line 17.02
 Span, ft 13.17
 Distance from center of gravity to elevator hinge line, in.
  Long tail length 252.7
  Short tail length 194.2

Vertical tail surfaces:
 Total area, sq ft 20.97
 Rudder
  Total 12.50
  Rearward of hinge line 10.57
 Span, ft 6.06
 Distance from center of gravity to rudder hinge line, in.
  Long tail length 266.4
  Short tail length 207.9

TABLE II.- CONFIGURATIONS TESTED ON THE MODEL

Tail length	$\frac{l}{b}$	Depth of ventral fin (fig. 4) (in.)	Data presented on	Tail damping ratio (reference 1)	Unshielded rudder volume coefficient (fig. 1 of reference 1)	Tail-damping power factor (reference 1)
Long	0.53	None	Chart 1	0.0263	0.0150	395×10^{-6}
Short	.41	0.50	Chart 1	.0261	.0160	418
Short	.41	0.75	Chart 2	.0293	.0160	469
Short	.41	1.00	Chart 2	.0323	.0160	517

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TABLE III.- MASS CHARACTERISTICS AND INERTIA PARAMETERS TESTED ON MODEL

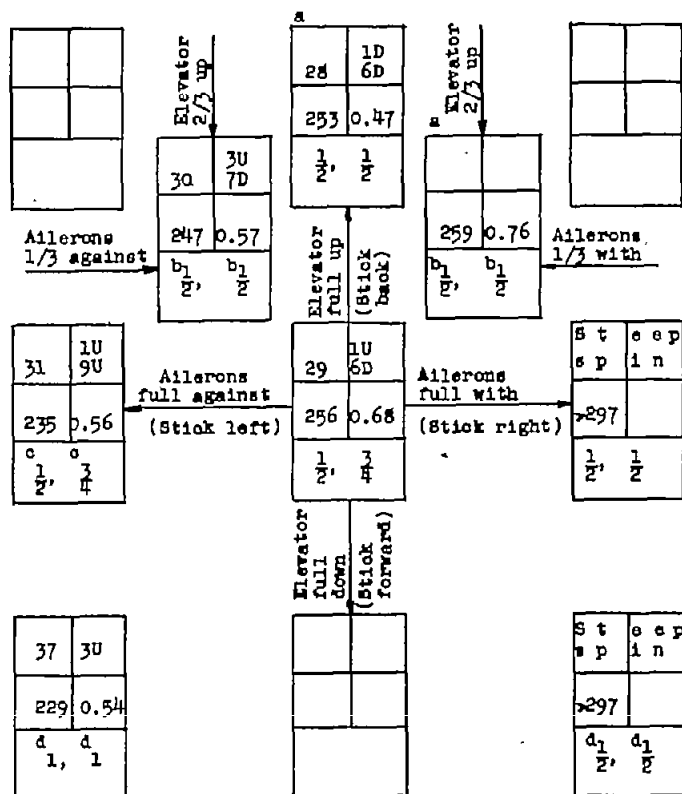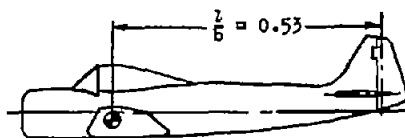[Model values are presented in terms of full-scale values.]

Config-uration	Tail length	Depth of ventral fin (in.)	Weight (lb)	Airplane relative density, μ		Center-of-gravity location		Moments of inertia (slug-feet²)			Inertia parameters		
				Sea level	10,000 feet	$x/\bar{c}$	$z/\bar{c}$	I_X	I_Y	I_Z	$\dfrac{I_X - I_Y}{mb^2}$	$\dfrac{I_Y - I_Z}{mb^2}$	$\dfrac{I_Z - I_X}{mb^2}$
1	Long	None	8436	11.2	15.1	0.275	0.021	4193	9397	12,979	-115×10^{-4}	-79×10^{-4}	194×10^{-4}
2	Short	$\left\{\begin{array}{c}0.50\\.75\\1.00\end{array}\right\}$	8441	11.2	15.2	.272	.016	4095	9303	12,870	-115	-79	194

CHART 1.- EFFECT OF TAIL LENGTH ON THE SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL
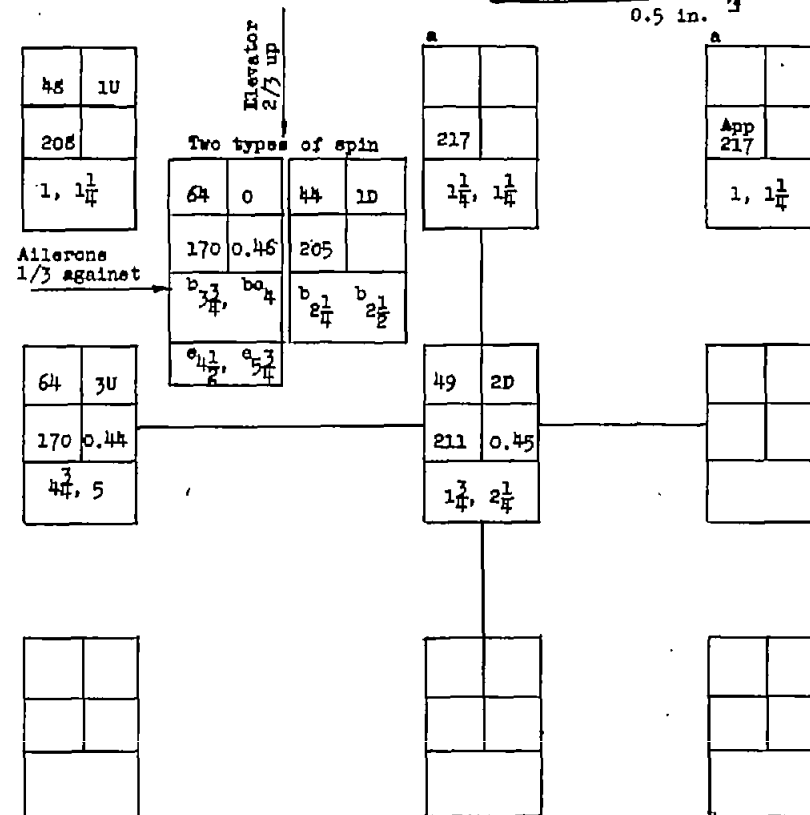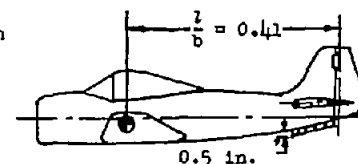
[Recovery attempted from and steady-spin data presented for rudder-full-with spins; recovery attempted by full rudder reversal unless otherwise indicated; right erect spins]

Configuration 1
(table III and fig. 5)

$\frac{l}{b} = 0.53$

Configuration 2 with 0.5-inch ventral fin
(table III and fig. 5)

$\frac{l}{b} = 0.41$

0.5 in.

Configuration 1

Elevator 2/3 up

a
28	1D 6D
233	0.47
$\frac{1}{2}$	$\frac{1}{2}$

a
30	3U 7D
247	0.57
$b\frac{1}{2}$	$b\frac{1}{2}$

Ailerons 1/3 against →

Elevator full up (Stick back)

a Elevator 2/3 up

259	0.76
$b\frac{1}{2}$	$b\frac{1}{2}$

← Ailerons 1/3 with

31	1U 9U
235	0.56
$c\frac{1}{2}$	$c\frac{3}{4}$

← Ailerons full against (Stick left)

29	1U 6D
256	0.68
$\frac{1}{2}$	$\frac{3}{4}$

Ailerons full with (Stick right) →

S t	e e p
s p	i n
>297	
$\frac{1}{2}$	$\frac{1}{2}$

Elevator full down (Stick forward)

37	3U
229	0.54
d 1,	d 1

S t	e e p
s p	i n
>297	
$d\frac{1}{2}$	$d\frac{1}{2}$

Configuration 2

48	1U
208	
1,	$1\frac{1}{4}$

Elevator 2/3 up
Two types of spin

64	0	44	1D
170	0.46	205	
$b3\frac{3}{4}$	$bo\frac{}{4}$	$b2\frac{1}{4}$	$b2\frac{1}{2}$
$e4\frac{1}{2}$	$e5\frac{3}{4}$		

Ailerons 1/3 against →

64	3U
170	0.44
$4\frac{3}{4}$, 5	

217	
$1\frac{1}{4}$,	$1\frac{1}{4}$

a
App 217	
1,	$1\frac{1}{4}$

49	2D
211	0.45
$1\frac{3}{4}$,	$2\frac{1}{4}$

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	ϕ (deg)
V (fps)	Ω (rps)
Turns for recovery	

a Model wanders.
b Recovery attempted by moving the rudder from full with the spin to 2/3 against the spin.
c Visual estimate.
d After recovery from the erect spin, the model enters an inverted spin.
e Recovery attempted by simultaneously reversing the rudder from full with the spin to 2/3 against the spin and the elevator from 2/3 up to 1/3 down.

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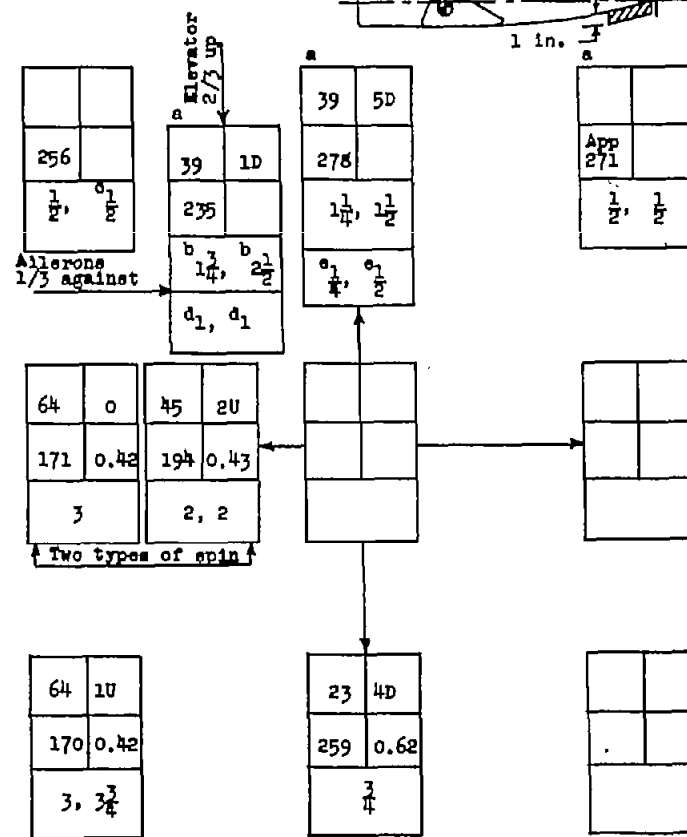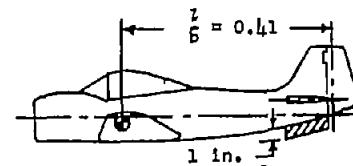CHART 2.- EFFECT OF VENTRAL FINS ON THE SPIN AND RECOVERY CHARACTERISTICS OF THE MODEL

[Configuration 2 (table III and fig. 5). Recovery attempted from and steady-spin data presented for rudder-full-with spins; recovery attempted by full rudder reversal unless otherwise indicated; right erect spins]

0.75-inch ventral fin installed
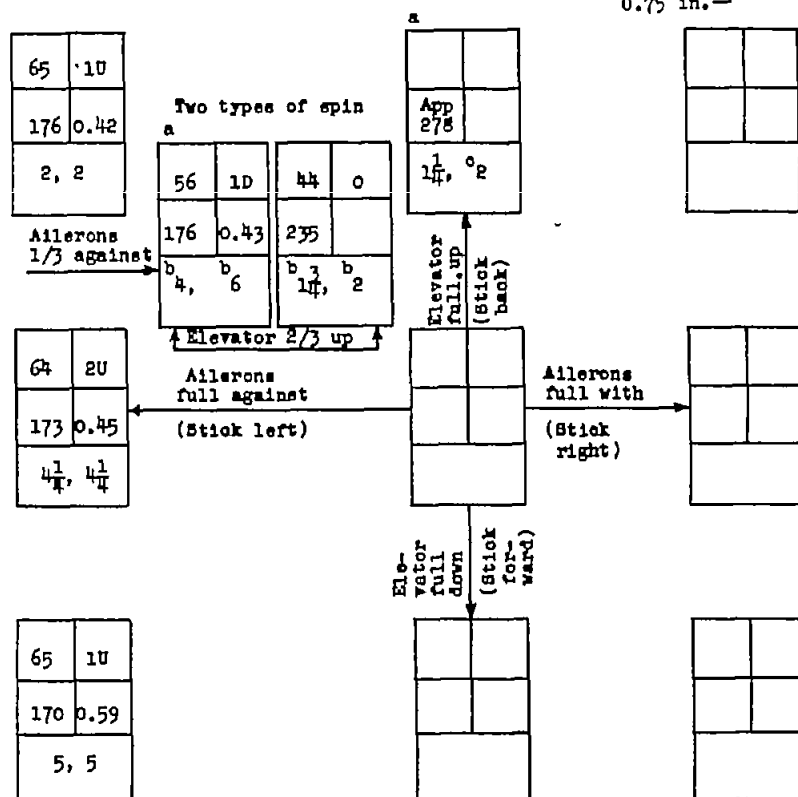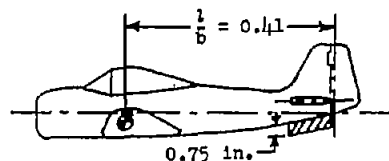
$\frac{l}{b} = 0.41$

0.75 in.

1.00-inch ventral fin installed

$\frac{l}{b} = 0.41$

1 in.

Two types of spin

65	·1U
176	0.42
2, 2	

Ailerons 1/3 against

56	1D
176	0.43
b4, b6	

44	0
235	
b1¼, b2	

Elevator 2/3 up

| App 278 |
| 1¼, °2 |

a

Elevator full up (Stick back)

Ailerons full against (Stick left)

64	2U
173	0.45
4¼, 4¼	

Ailerons full with (Stick right)

Elevator full down (Stick forward)

65	1U
170	0.59
5, 5	

Elevator 2/3 up

| 256 |
| ½, d½ |

Ailerons 1/3 against

39	1D
235	
b1¼, b2½	
d1, d1	

a

39	5D
278	
1¼, 1½	
e¼, e½	

a

| App 271 |
| ½, ½ |

64	0
171	0.42
3	

45	2U
194	0.43
2, 2	

Two types of spin

64	1U
170	0.42
3, 3¾	

23	4D
259	0.62
¾	

a Model wanders.
b Recovery attempted by moving the rudder from full with the spin to 2/3 against the spin.
c Visual estimate.
d Recovery attempted by simultaneously reversing the rudder from full with the spin to 2/3 against the spin and the elevator from 2/3 up to 1/3 down.
e Recovery attempted by simultaneously reversing the rudder from full with the spin to 2/3 against the spin and the elevator from full up to 1/3 down.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

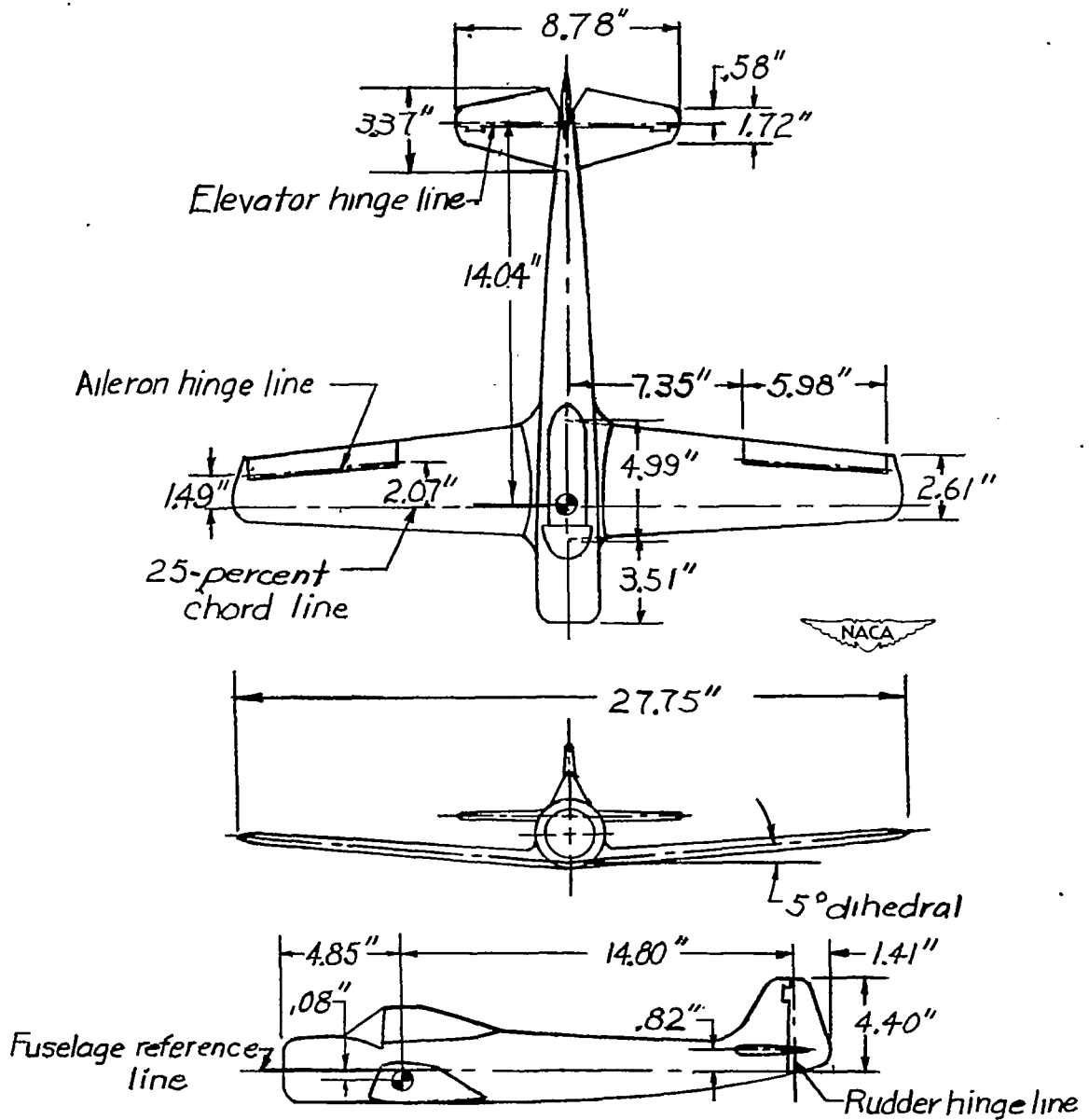| α (deg) | θ (deg) |
| V (fps) | Ω (rps) |
| Turns for recovery | |

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Figure 1.- Three-view drawing of model with long tail length as tested in the Langley 20-foot free-spinning tunnel. Center of gravity at 27.5 percent mean aerodynamic chord.
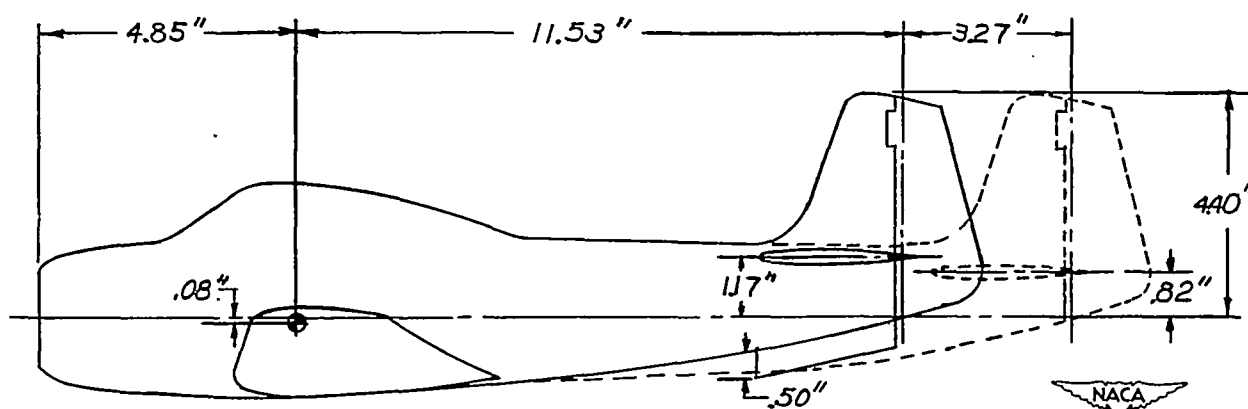
Figure 2.- Comparison of the long and short tail lengths tested on the model. Center of gravity at 27.5 percent mean aerodynamic chord.
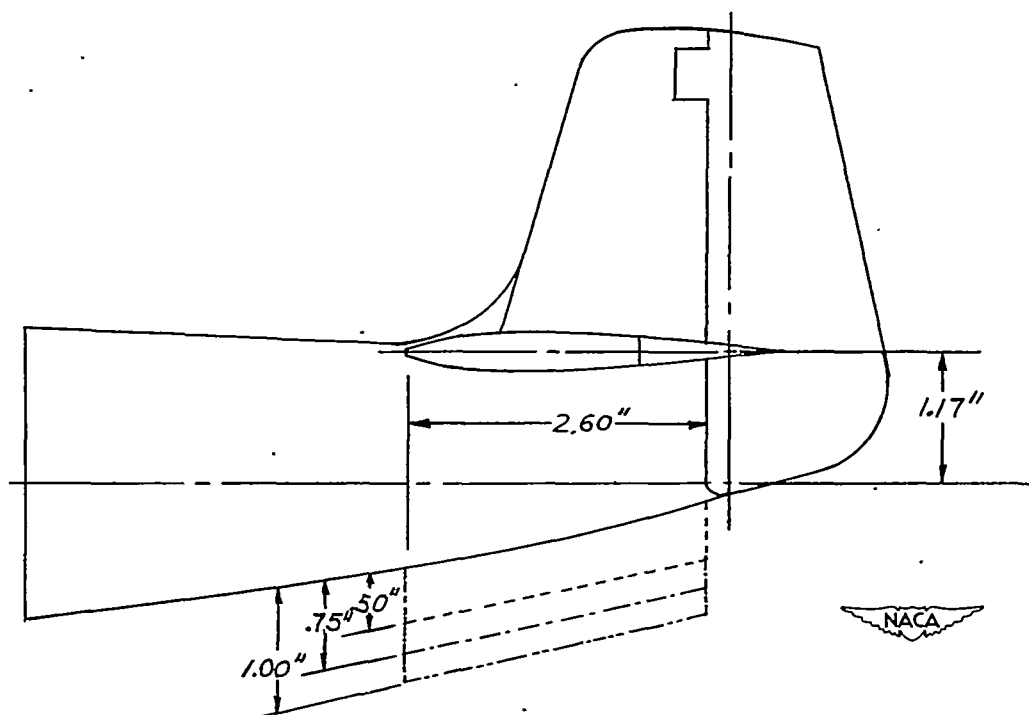

Figure 3.- Size and location of ventral fins tested on model with short tail length installed.

Figure 4.- Photograph of the model spinning in the Langley 20-foot
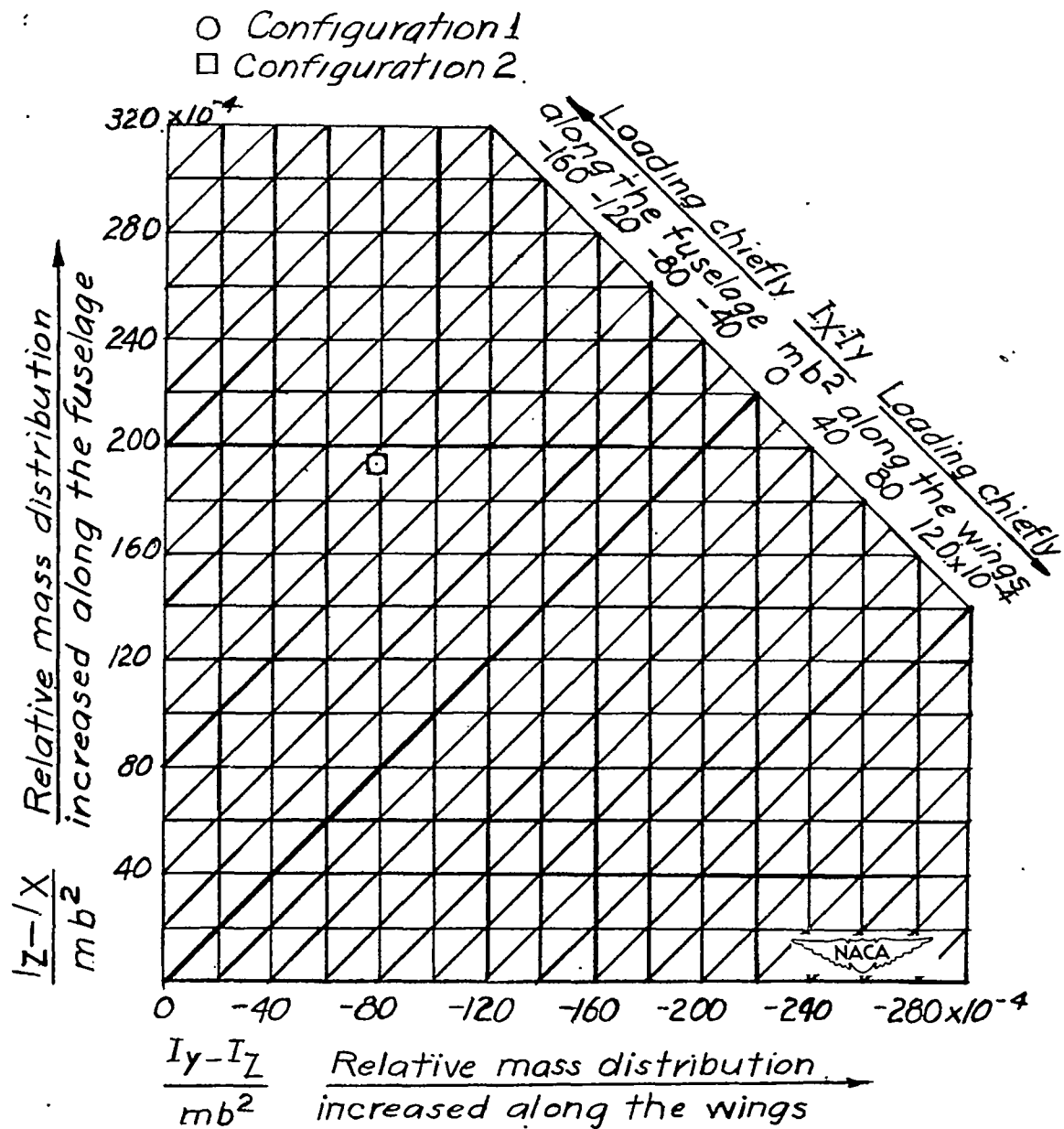free-spinning tunnel.

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Figure 5.- Inertia mass parameters for various model configurations tested. (Loadings listed in table III.)